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# THE ALLOCATION OF TIME TO TEMPORALLY DEFINED BEHAVIORS: RESPONDING DURING STIMULUS GENERALIZATION

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In one stimulus condition, reinforcement depended on rats holding a lever for a duration having both minimum and maximum boundaries. During a second light intensity, reinforcement was not available for some rats; for others, reinforcement depended on a second response duration requirement. Generalization test stimuli controlled the same response durations found during training, and the amount of time allocated to a given response duration depended on the proximity of the test stimulus to the training stimulus which controlled that particular duration. The results indicated that a gradient of stimulus control does not reflect an underlying continuous change in responding, but is a result of the mixing of responses previously controlled by stimuli present during conditioning.

*Key words:* stimulus control, time allocation, temporal control, response mixing, response continuum, peak shift, temporally extended operant, lever holding, rats

Research has suggested that the sloping gradient of response rate found during stimulus generalization does not reflect a continuous change in responding. Instead, the results have indicated that the generalization gradient is a result of the mixing of various responses. These responses consist of the local rates of response controlled by the stimulus present during training and other, unmeasured behaviors (Blough, 1963; Crites, Harris, Rosenquist, & Thomas, 1967; Sewell & Kendall, 1965).

When variants of a response are differentially reinforced in the presence of discriminative stimuli in an effort to label responses, testing with intermediate stimuli has usually resulted in the mixing of the two forms of the response. In an experiment by Migler (1964), reinforcement depended on rats pressing a second lever only after either 0 or 6 sec had elapsed since pressing a first lever, and the appropriate interval was signaled by a click frequency. With intermediate test stimuli, lever-to-lever response durations were either short or clustered around the 6-sec point. Using a similar temporally extended operant, mixing has been obtained with pigeons (Scheuerman, Wildemann, & Holland, 1978). In addition, Wildemann and Holland (1972) obtained mixing using a continuous spatial response dimension. Intermediate stimuli did not result in pigeons pecking an intermediate location.

Some aspects of these studies may limit the generality of the mixing hypothesis. The response requirement used in Migler's study was either a short lever-to-lever interval or a 6-sec minimum interval. Mixing might have been less likely if both response requirements necessitated some minimum duration (cf. Boakes, 1969; however, see Scheuerman, et al., 1978). Also, mixing of responses during generalization has been found in studies in which different forms of a behavior have been differentially reinforced (i.e., two lever-to-lever durations or pecking different locations). The present experiment explored the generality of the phenomenon of mixing by using different procedures which included training conditions in which either one or two forms of a response were reinforced.

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## METHOD

### *Subjects*

Twenty-two Sprague-Dawley rats were maintained at 80% of their free-feeding weights. Nine (R3 through R13) previously served in a one-trial conditioned suppression experiment which involved neither lever-pressing nor visual discriminations. One (R2) had served in a pilot study in the present apparatus and had been exposed to various variable-interval schedules, extinction, and reconditioning for the two duration criteria used in the current study. The remaining 12 rats were experimentally naive.

### *Apparatus*

A Lehigh Valley Electronics retractable lever was mounted on the left side of the experimental chamber 3.8 cm above the grid floor. The lever protruded 2.2 cm into the cage, was 4.8 cm wide, and required a static force of .3 to .4 N to actuate the microswitch. The 45-mg Noyes pellets used as reinforcers were delivered into a food cup located on the right side of the cage. A stimulus light (a 4.6-W, #1893 lamp covered by a milk-white jewel) was located 6.3 cm above the lever. Various voltages were applied across the lamp by placing one of several rheostats in series with the lamp and its regulated 15-V-dc power source. Light intensity values, measured at the stimulus lamp jewel by a Tektronix J16 digital photometer, were 10, 27, 60, 135, and 300 cd/m$^2$ (approximately equal log units), and are denoted Stimulus 1 through 5 respectively (dim to bright). The cage was set in a wood enclosure lined with flat white acoustic tile. White noise and ventilation fans provided masking noise. The control equipment, a ModComp II digital computer interfaced with electromechanical equipment, was housed in adjacent rooms. Inputs were serviced every 50 msec by the computer.

### *Procedure*

*Preliminary training.* Subjects were shaped by successive approximations to press the lever in the presence of the stimulus later to be correlated with reinforcement. Reinforcers were delivered upon lever release. In Condition 1, in which there was no time requirement, the schedule of reinforcement was changed from continuous reinforcement to variable-interval (VI) 20-sec over several days. The VI schedules consisted of three repetitions of six intervals selected according to the method described by Fleshler and Hoffman (1962).

For Conditions 2 and 3, the criterion response, consisting of a minimum time requirement between lever depression and release, was gradually increased until a duration of 4 to 6 sec (5 to 7.5 sec for R2) was reached. Each criterion response was reinforced.

For all conditions, the training stimuli were either S1 and S5 (S1/S5) or S2 and S4 (S2/S4). The stimulus intensity associated with the response requirement was counterbalanced for stimulus intensity within a condition.

*Discrimination training.* Discrimination training began for subjects in Condition 1 after the VI 20-sec schedule had been in effect for 14 days (R11, R12, R13) or 3 days (R41, R42, R43, R44), and for the subjects of Conditions 2 and 3 after 2 weeks (R2 through R10) or 1 week (R21 through R34) of exposure to the criterion response.

For Conditions 1 and 2, reinforcement was not available during the second training stimulus (S−). For Condition 3, the criterion response during the second training stimulus was 1 to 1.5 sec (2 to 3 sec for R2). No shaping of the shorter criterion response was necessary. The stimulus with the shorter requirement is referred to as $S+_S$, and the stimulus with the longer duration requirement is $S+_L$.

All stimulus presentations were 60 sec; however, in order to minimize disruption of lever-holding during the original training stimulus, the frequency of presentation of the second training stimulus was gradually increased until the stimuli were presented in a quasi-random order such that no stimulus occurred more than three times in succession with no time lags between stimulus presentations.

The VI schedules were gradually introduced in Conditions 2 and 3. A VI 20-sec schedule for the criterion response(s) was chosen for most subjects, because this VI value resulted in little disruption of holding performance when gradually introduced, and because the longest intervals (56 sec) were close to the duration (60 sec) of the probe stimuli. Table 1 shows the specific schedules and training conditions. The final VI schedules were in effect for 12 to 26 days prior to generalization testing.

Table 1

Subjects with terminal schedules of reinforcement and duration requirements (in sec) for each stimulus used during training.

| | | S+ or $S+_{Long}$ | | | S− or $S+_{Short}$ | | |
|---|---|---|---|---|---|---|---|
| *Subject* | *Condition* | *Duration* | *Schedule* | *Stimulus* | *Duration* | *Schedule* | *Stimulus* |
| R11 | 1 | 0-infinite | VI 20 | S1 | — | EXT | S5 |
| R41 | 1 | 0-infinite | VI 20 | S1 | — | EXT | S5 |
| R12 | 1 | 0-infinite | VI 20 | S5 | — | EXT | S1 |
| R42 | 1 | 0-infinite | VI 20 | S5 | — | EXT | S1 |
| R43 | 1 | 0-infinite | VI 20 | S2 | — | EXT | S4 |
| R13 | 1 | 0-infinite | VI 20 | S4 | — | EXT | S2 |
| R44 | 1 | 0-infinite | VI 20 | S4 | — | EXT | S2 |
| R3 | 2 | 4-6 | VI 20 | S1 | — | EXT | S5 |
| R21 | 2 | 4-6 | VI 20 | S1 | — | EXT | S5 |
| R4 | 2 | 4-6 | VI 15 | S5 | — | EXT | S1 |
| R22 | 2 | 4-6 | VI 20 | S5 | — | EXT | S1 |
| R23 | 2 | 4-6 | VI 20 | S2 | — | EXT | S4 |
| R6 | 2 | 4-6 | VI 20 | S4 | — | EXT | S2 |
| R24 | 2 | 4-6 | VI 20 | S4 | — | EXT | S2 |
| R7 | 3 | 4-6 | VI 20 | S1 | 1-1.5 | VI 21 | S5 |
| R31 | 3 | 4-6 | VI 20 | S1 | 1-1.5 | VI 20 | S5 |
| R8 | 3 | 4-6 | VI 20 | S5 | 1-1.5 | VI 15 | S1 |
| R32 | 3 | 4-6 | VI 20 | S5 | 1-1.5 | VI 20 | S1 |
| R2 | 3 | 5-7.5 | VI 20 | S2 | 2-3 | VI 20 | S4 |
| R33 | 3 | 4-6 | VI 20 | S2 | 1-1.5 | VI 20 | S4 |
| R10 | 3 | 4-6 | VI 20 | S4 | 1-1.5 | VI 22 | S2 |
| R34 | 3 | 4-6 | VI 20 | S4 | 1-1.5 | VI 20 | S2 |

*Probe tests.* When there appeared to be no systematic increases or decreases in the percentage of time spent in criterion-duration responding, generalization testing was begun. Testing was conducted through a probe procedure in which one of five different light intensities was presented with extinction in effect. The 1-min probes occurred between the 15th and 48th min of the 60-min sessions. They were preceded by a stimulus that had been present for only 1 min. Probes followed each other by no less than 5 min. All probes followed one training stimulus on half the sessions and the other stimulus in alternate sessions. Each of these session types was subdivided so the sequence of probes differed within alternate pairs of sessions. For animals trained with S1/S5, the sequences of probes were 2, 5, 3, 1, 4 and 4, 1, 3, 5, 2. For subjects trained with S2/S4, the sequences of probes were 1, 4, 3, 2, 5 and 5, 2, 3, 4, 1. Each probe stimulus was presented once per day for 24 sessions, providing 24 min at each stimulus condition (except for R13 which had only 19 min due to a fatal illness).

## RESULTS

*Condition 1.* Figure 1 shows the relative generalization gradients of response frequency. For all subjects, with the exception of R41, clear evidence of control by stimulus intensity was shown by the frequency of responding. More responses were emitted during S+ regardless of whether that stimulus was the brighter or dimmer of the discriminative stimuli. The number of responses decreased as the intensity of the test stimuli approached S−.

Since Condition 1 responses were generally of very short duration, rate of response was

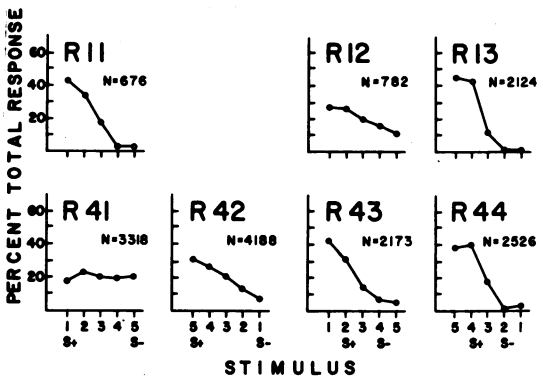


Fig. 1. Relative generalization gradients for subjects of Condition 1 and the number of responses on which the gradients are based. S1 is always the dimmest and S5 the brightest stimulus.

used as a performance measure. However, when responses are not "instantaneous" and take varying amounts of time to emit, rate may not be the most appropriate measure (Baum & Rachlin, 1969; Gray, 1976; Shimp, 1976). Because many occurrences of a short-duration response may amount to a small percentage of time and a few long-duration responses may amount to a large percentage of time, the distribution of the accumulated amount of time devoted to responses of various durations provides a better description of the overall activity of the subject during the experimental session than would a simple frequency distribution of responses. (The approximate frequency of responses at any class interval may be obtained by dividing the time accumulated in that interval by the midpoint of the interval.) Relative time allocation distributions for bar-holding (BAR) and interresponse times (IRTs) are shown in Figures 2 through 5. The total area under the BAR and IRT curves for each subject (including the percentage of time spent in IRT>9 sec shown in parentheses) equals the 24 min of exposure to that stimulus. Figure 3 displays time-allocation data for R41 in Condition 1. The time-allocation data show that the behavior of R41 was under stimulus control in that the pattern of both bar-holding and IRTs during S+ differed from that occurring during S−.

*Condition 2.* Figures 2 and 3 show that the behavior of all subjects was affected by having reinforcement depend on a specific response duration. In the presence of S+, the proportion of time spent holding the lever was greatest for those durations that produced food.

The modes of the distributions at S+ were between 4 and 6 sec, and usually remained in that range during generalization testing. During generalization, the shapes of the distributions remained similar, but the amount of time

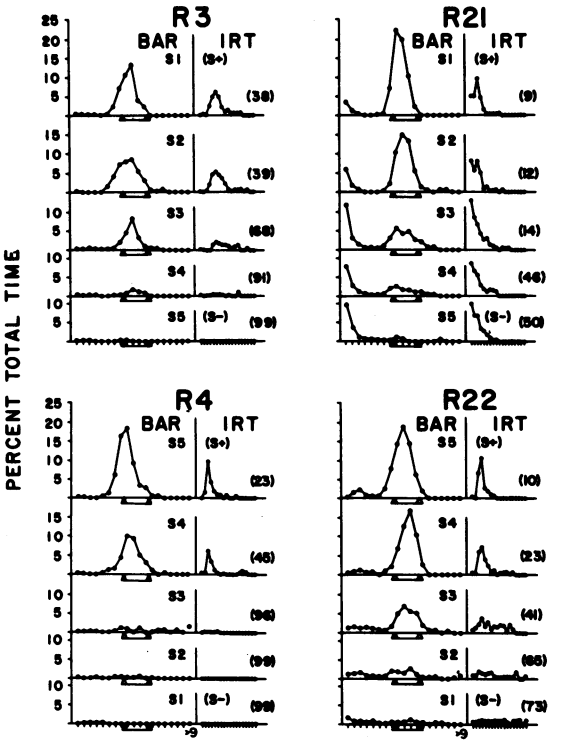


Fig. 2. Condition 2 relative time allocation distributions for subjects trained with S1/S5. BAR durations reinforced during training are shown on the abscissa. Numbers in parentheses denote percentage of time engaged in IRT behaviors greater than 9 sec or which overlapped stimulus periods.

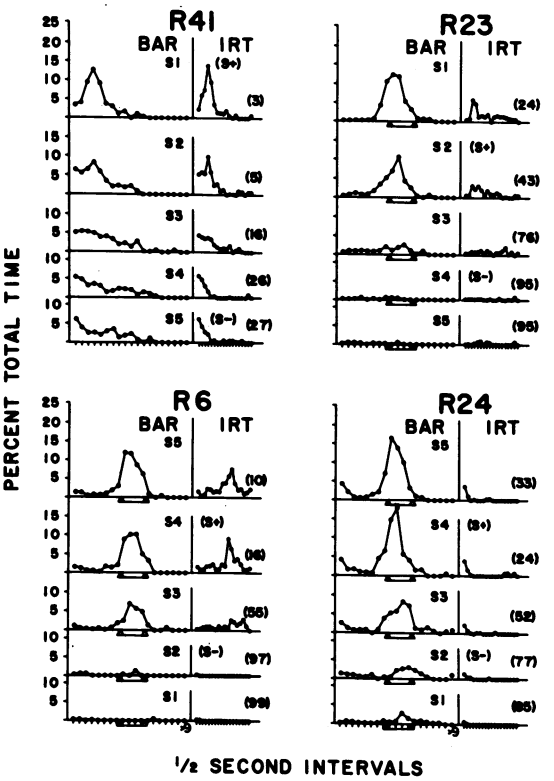


Fig. 3. Condition 2 relative time allocation distributions for subjects trained with S2/S4. BAR durations reinforced during training are shown on the abscissa, except for R41, a subject from Condition 1 with no BAR duration requirements for reinforcement. Numbers in parentheses denote percentage of time engaged in IRT behaviors greater than 9 sec or which overlapped stimulus periods.

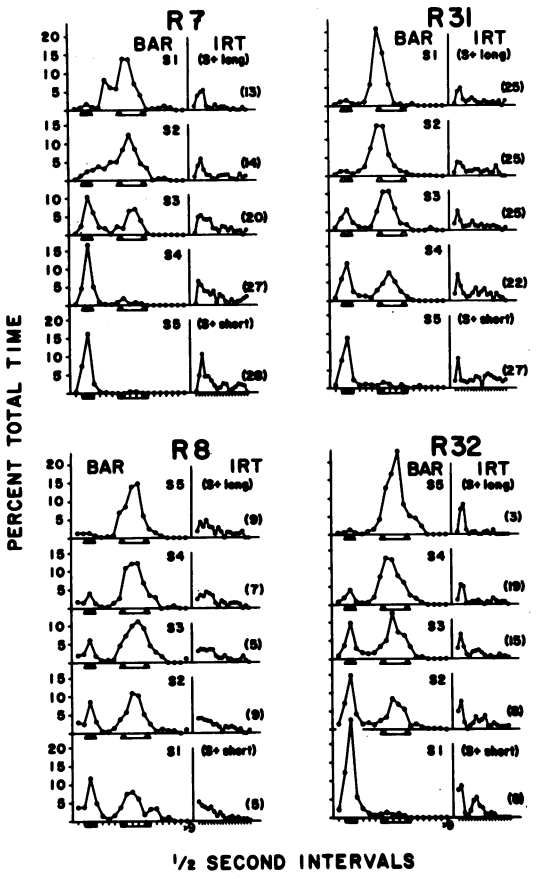


Fig. 4. Condition 3 relative time allocation distributions for subjects trained with S1/S5. BAR durations reinforced during training are shown on the abscissa. Numbers in parentheses denote percentage of time spent in IRT behaviors greater than 9 sec or which overlapped stimulus periods.

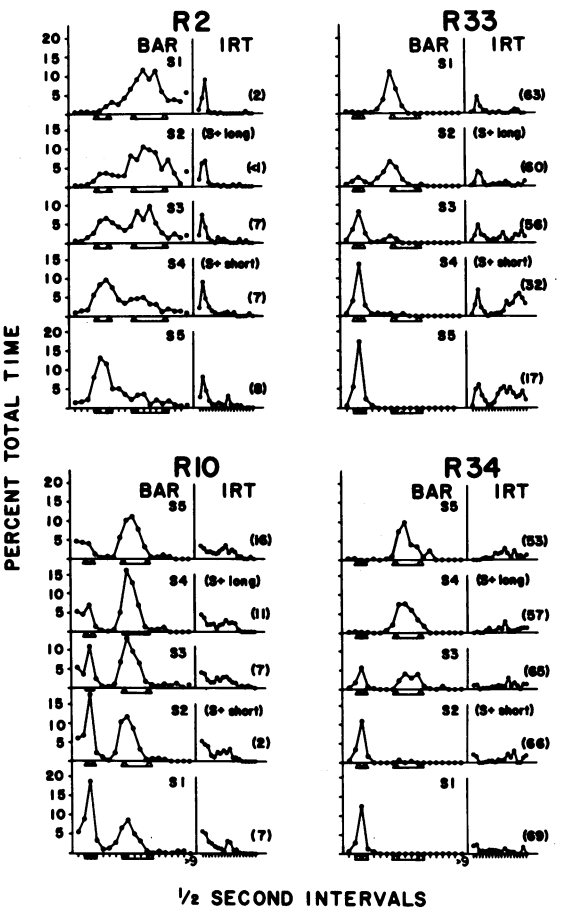


Fig. 5. Condition 3 relative time allocation distributions for subjects trained with S2/S4. BAR durations reinforced during training are shown on the abscissa. Numbers in parentheses denote percentage of time spent in IRT behaviors greater than 9 sec or which overlapped stimulus periods.

spent engaging in S+ controlled responding decreased. Intermediate stimuli did not result in a wider distribution of BAR responses, although the S− did occasion some durations greater than 6 sec.

*Condition 3.* Figures 4 and 5 show that the bar durations of all subjects were controlled by the training stimuli when bar-holding was reinforced during both training stimuli. The results paralleled those of Condition 2 in that as the stimuli were varied, mixtures of the responses controlled by the training stimuli were emitted to the test stimuli. In no case did an intermediate stimulus result in any increase in intermediate response durations.

This general result occurred despite individual differences in the characteristics of responding. Some subjects emitted few responses in the presence of one training stimulus that were appropriate to the other training stimulus (R7, R31, R33, R32, and R34). There were degrees of "inaccuracy"—responses falling just outside the criteria (cf. R33 and R34). The distributions varied in the amount of overlap (cf. R2 and R34) and in the amount of total responding (cf. the IRT overflow percentages in parentheses of R33 and R8). Although most subjects obtained 45 to 55% of the reinforcers in each training stimulus, R31 received 40 to 45% for the longer duration response, and R33 received a small and variable number of reinforcers (7 to 25%) for the long-duration response. For each subject, however, informal observations failed to reveal any obvious dif-

ferences in the topographies of lever-holding during the two training stimulus conditions.

*Peak shift.* Subjects trained with S2/S4 were tested with stimuli outside the range of the training stimuli. When such a stimulus was adjacent to S+, the number of responses that were emitted by three of the four subjects of Condition 1 exceeded the number that were emitted to S+ (peak shift). When the stimulus was adjacent to S−, two of those subjects (R12 and R43) exhibited a "negative peak shift"—fewer responses emitted to the test stimulus than were emitted to S−.

Figures 3 and 5 show the pattern of responding that occurred when test stimuli outside the range of the training stimuli were presented to subjects of Conditions 2 and 3. Data for R23 and R33 are also shown in Table 2. While the pattern of responding to the test stimulus resembled the pattern of responding to the adjacent training stimulus, the *amount* of that pattern of responding which was controlled by the test stimulus often exceeded the amount of that responding to the training stimulus. For Condition 2 (Figure 3) this refers both to an increase in S+ controlled responding to the stimulus next to S+ and a further decrease in S+ controlled responding next to S−. For Condition 3 (Figure 5) there was often an increase in responses appropriate to the adjacent S+ and a decrease in responses appropriate to the distance S+.

*Interresponse times.* In both Conditions 2 and 3 the shorter IRTs appeared to be related to lever-holding. Casual observations during training revealed that subjects tended to release the lever and either press it again immediately or after momentarily approaching the food receptacle. Both patterns would result in IRTs of less than 3 sec. In Condition 2, as the intensity of S− was approached, there was a decrease in the amount of time spent engaging in the shorter IRTs that occurred during S+ and a progressive increase in the percentage of time engaging in IRTs greater than 9 sec.

## DISCUSSION

Condition 1, involving no duration requirement, showed that responding was under control of light intensity, regardless of whether S+ was dim or bright. Condition 2 involved a temporal criterion during one stimulus (S+) and extinction in the other (S−). If conditioned responding mixed with other, unmeasured behavior, durations of lever-holding emitted to the training stimulus values should have been similar to those emitted to S+. The results indicated that the performance during

Table 2

Various duration lever-holding responses are summarized by both their frequency of occurrence and amount of time in sec devoted to those responses for R23 and R33. The responses which were less than .5 sec are included because these short duration responses occasionally amounted to a large percentage of the total responses, even though the time allocated to such responses was relatively small. The total amount of time in the presence of each stimulus was 1440 sec.

| | *R23, Condition 2* | | | | | |
|---|---|---|---|---|---|---|
| | *<0.5 sec* | | *4-6 sec* | | *Total* | |
| *Stimulus* | *Freq* | *Time* | *Freq* | *Time* | *Freq* | *Time* |
| S1 | 19 | 4 | 99 | 463 | 196 | 734 |
| S2 (S+) | 23 | 5 | 68 | 311 | 174 | 533 |
| S3 | 22 | 5 | 18 | 89 | 93 | 201 |
| S4 (S−) | 14 | 3 | 3 | 13 | 26 | 36 |
| S5 | 21 | 5 | 1 | 5 | 42 | 36 |

| | *R33, Condition 3* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *<0.5 sec* | | *1-1.5 sec* | | *4-6 sec* | | *Total* | |
| *Stimulus* | *Freq* | *Time* | *Freq* | *Time* | *Freq* | *Time* | *Freq* | *Time* |
| S1 | 25 | 7 | 4 | 5 | 27 | 115 | 134 | 371 |
| S2 (S+ Long) | 24 | 7 | 28 | 34 | 24 | 104 | 161 | 360 |
| S3 | 26 | 7 | 99 | 117 | 3 | 12 | 223 | 262 |
| S4 (S+ Short) | 15 | 4 | 166 | 194 | 2 | 9 | 287 | 333 |
| S5 | 20 | 6 | 212 | 247 | 0 | 0 | 353 | 374 |

generalization was a result of mixing of the previously conditioned response with other behavior from a different response class.

In Condition 3, different durations were differentially reinforced during the two training stimuli. In contrast to Boakes' (1969) report, intermediate durations did not occur with intermediate stimuli. Results consistent with the mixing hypothesis occurred despite idiosyncratic patterns of responding. Further, these results were obtained when the temporally extended operant was maintained by a VI schedule of reinforcement, thereby aiding possible comparison to situations in which the duration of the response is free to vary, such as Condition 1.

Some subjects of Condition 1 showed peak shift (Hanson, 1959). If peak shift is an indication that more of the conditioned responding occurred, then some subjects in Conditions 2 and 3 also showed "peak shift" in that there was an increase in the amount of the behavior appropriate to the adjacent training stimulus when stimuli outside the range of the training stimuli were presented. In this sense, negative peak shift occurred when there was a further decrease in the amount of the behavior appropriate to the distant training stimulus. These peak shifts were not the result of any change in the response durations, but were the result of differing amounts of time allocated to the response of lever-holding.

In general, the amount of time spent engaging in a response decreased as the stimulus conditions departed from the stimulus conditions in which the response was acquired, regardless of whether one or two criterion responses were explicitly conditioned. Durations that did not occur during the training stimulus conditions did not appear when test stimuli were introduced. The data are thus consistent with the position that responding in generalization tests is the outcome of a process of mixing previously conditioned responses (Bushnell & Weiss, 1978; Crites, et al., 1967; Sewell & Kendall, 1965).

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